Video game-based learning for teaching building thermodynamics and control of HVAC systems

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Video game-based learning for teaching building thermodynamics and control of HVAC systems

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Abstract

This paper presents GEENIE, a video game simulating the thermodynamics of a building. The game is used to introduce a university course about control of Heating, Ventilation and Air Conditioning systems. The purpose of the game is to rapidly engage the students with the importance of having automated control systems in buildings to ensure a high quality indoor environment with minimum energy use. GEENIE consists of an arcade video game station with physical controllers allowing players to adjust the heating, cooling, ventilation, lighting and shading device of the simulated building subjected to dynamic boundary conditions. A score is calculated as a function of the average indoor comfort and the energy use. Reaching a higher score motivates the players to optimize their manual control strategy, but also to understand building thermodynamics and indoor comfort. Moreover, the players can compete against automated controllers. The latter outperform human manual control, emphasizing the importance of the course's topic.

Description of the game

If a picture is worth a thousand words, how many words is a game worth then?

Gameplay and game objective

GEENIE (Gaming Engine for ENergy and Indoor Environment) is an interactive video game simulating the thermodynamics of a building. The GEENIE has been developed in the LabVIEW programming environment (developed and commercialized by *National Instruments)*.

Figure 1: A player with the video game GEENIE.

Through this video game, the students (players) can experience the dynamics of the indoor environment, and the interconnections between the different HVAC systems and IEQ parameters, which emphasizes the importance of searching for holistic compromises, rather than local optimum.

The GEENIE consists of an arcade video game station allowing players to adjust (with hand controllers) the heating, cooling, ventilation, lighting and shading device of a simulated building (see Figure 1 and Figure 2). The players must control the power/activation level of those systems to keep the indoor operative temperature, CO_2 concentration, and illuminance as close as possible to the comfort optimum, while the dynamic boundary conditions (outdoor weather conditions, people loads) induce variations to the system.

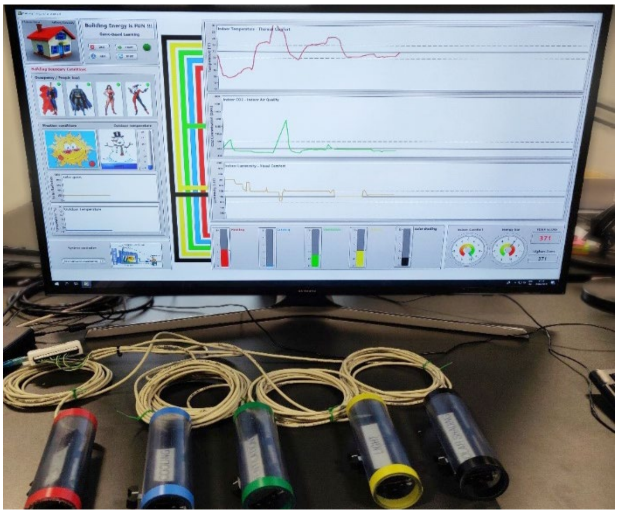

Figure 2: View of the video game GEENIE with the five controllers (sliders) for the HVAC systems.

During the two-minute duration of the game, an IEQ index (from 0 to 10 points) is calculated as a function of the indoor thermal comfort, indoor air quality and indoor illuminance of the simulated building. To maximize this index, the players must keep the indoor operative temperature at 22 °C, the illuminance at 400 lux, and the CO_2 concentration at 600 ppm or lower. Similarly, an energy usage penalty index (from 0 to 10 points) is calculated as a function of the power/activation level of the building systems. The players must minimize this penalty index by keeping the intensity of the HVAC systems as low as possible, which can induce a compromise with the IEQ index.

Both the IEQ and energy usage indexes are clearly visible on the game interface as live indicators of the current performance. A combined score is calculated as the cumulated energy usage penalty index subtracted from the cumulated IEQ index. At the end of the two-minute game, the final score is displayed and recorded. The objective of the game is to achieve the highest total score possible.

Players are encouraged to replay the game to improve their total score. The game duration is kept short so that the players stay focussed and are motivated to replay the game several times using different strategies.

The game can be played in two different modes: a "tutorial" mode or a "real game" mode. The tutorial mode has constant boundary conditions and is only intended for the players to get accustomed to the manual control sliders, the game interface and the dynamics of the simulated indoor environment (presented hereafter in the context of steady-state boundary conditions):

- Higher heating power increases the indoor temperature.
- Higher cooling power decreases the indoor temperature.
- Higher ventilation rate decreases the indoor CO_2 concentration, increases the ventilation heat losses.
- Higher artificial lighting increases the illuminance and increases the internal heat gains.
- Higher activation of the solar shading device decreases the solar gains and the indoor illuminance during daytime.

Because the tutorial mode has constant boundary conditions, it is fairly easy for the players to reach a good total score. However, the score is not recorded at the end of a game in tutorial mode. Conversely, the "real game" mode has time-varying boundary conditions, which is realistic since real-world buildings are always subjected to dynamics boundary conditions. It is thus much more challenging for the players to constantly adjust the intensity of the different HVAC systems to achieve good IEQ. Only the score of the "real game" mode is recorded and considered for the competition between players.

Instead of the manual control by the players, the game can also be run in "automated" mode with the computer adjusting automatically the intensity of the HVAC systems to maintain a good IEQ. The "automated" mode is used for the demonstration of automated controllers in buildings. Three automated controllers can be selected: "ON/OFF control", "Smart control", "Perfect control".

Video game interface

Figure 3 shows an overview of the GEENIE user interface. Figure 4 details the different parts of this graphical user interface (GUI):

1. The main game management to start or interrupt a new game, reset the game to the starting point, open the help file, and close the video game interface.
2. The boundary conditions window provides a live overview of (A) occupancy level (B) winter/summer season, (C) night/daytime, (D) outdoor temperature, and (E) solar irradiation.
3. Selection of the controller type: "manual control" (HVAC management by human players), "ON/OFF" control, "Smart" control, or "Perfect" control.
4. The five vertical sliders indicators show the current power/activation level of the five building systems.
5. The three graphs display the history-curves of the three IEQ parameters of interest in the game: operative temperature (red line), CO_2 concentration (green line) and illuminance (yellow line). The thick black lines indicate the optimal value of the respective IEQ parameters. The black dotted lines represent an acceptable range for the IEQ parameters.
6. The gauge indicators show the current IEQ index and the current energy usage penalty index. The cumulated total score for the current game is listed in the lower corner, next to highest scores for human players and automated controllers, respectively.

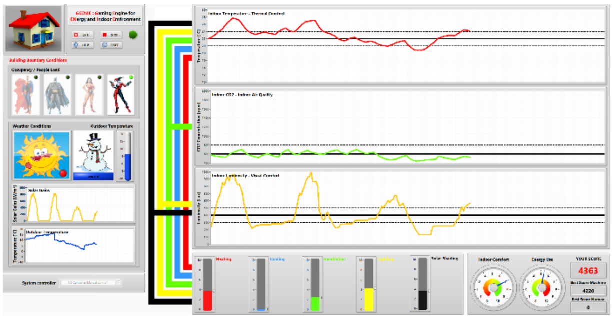

Figure 3: Overview of the GEENIE interface.

Figure 4: Different elements of the GEENIE interface.

Gamification and motivation

The main gamification aspect of the GEENIE lies in the competitive element of striving to beat the highest scores. This is classic game mechanics to engage students and trigger their curiosity about the topic of interest that is introduced by the GEENIE.

During the game and in between the different games, the teachers can exchange with the players to explain the underlying "logic" of the building thermodynamics and the pitfalls to avoid when controlling the HVAC systems. This includes guiding players to find a good compromise between energy use and IEQ performance. Moreover, the students are encouraged to discuss with each other to exchange their understanding of the game and adopt an optimum control strategy.

The game is designed to be difficult for human players. Consequently, the automated controllers (particularly the "Smart" and the "Perfect" controllers) largely outperform the players' manual regulation. This emphasizes the limitations of humans for continuously adjusting the intensity of HVAC systems, and thus highlights the importance of having reliable building automation.

HVAC controllers

If the game runs in "automated" mode, the computer controls the HVAC systems with three possible control strategies: "ON/OFF" control, "Smart" control and "Perfect" control. These denominations are purposely kept simple as they are intended for an audience with no background in control systems. The heating and the cooling systems are regulated according to the indoor temperature. The ventilation system is regulated according to the indoor CO_2 concentration. The artificial lighting and the shading device are regulated according to the indoor illuminance. For each of the aforementioned process variable, the controller's setpoint is kept constant at a value corresponding to the highest IEQ index: 22 °C for heating and cooling; 600 ppm for ventilation; 400 lux for lighting and shading device.

The "ON/OFF" control mode consists in an ON/OFF controller for the heating, cooling and ventilation systems, and a two-position controller for lighting and shading device with pre-set positions for daytime and night-time. The "Smart" control mode consists of a PI (Proportional and Integral) controller for each of the five HVAC systems. Finally, the "Perfect" control is a model-based control that calculates the exact needs for ventilation rate, heating, cooling, lighting and shading position to compensate for the current deviation between the three process variables and their respective setpoint. These adjustments to the HVAC systems operation are applied at the next time step. However, this "Perfect" controller does not take into account the change of boundary conditions at the next time steps: it is not a model predictive controller.

Conclusion

This article has presented GEENIE, an interactive video currently used to introduce a university course about control of HVAC systems in buildings. This video game has been found to be very effective at engaging the students with the main topics of the course. The players are competing for the highest score by manually controlling the intensity of different HVAC systems to maintain the best IEQ possible with the minimum energy use in a simulated building. This classic game mechanics engages the players and trigger their curiosity to learn more about the topics of building thermodynamics, IEQ, and control systems. It also enables the supervising teachers to exchange with the players about the relationships between the different HVAC systems and their impact of the IEQ parameters, and the common issues and mistakes occurring in building automation. In addition, the players are invited to observe the game being run in "automated" mode in which the computer regulates automatically the HVAC systems. The game is purposely designed to be difficult for human players. Therefore, the automated control largely outperformed the latter in achieving optimum IEQ with the lowest energy use possible, emphasizing the importance of building automation, the course's main topic.